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LONG PAPER

# Improvement in environmental accessibility via volunteered geographic information: a case study

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**Abstract** Although geo-crowdsourcing approaches provide an opportunity to collect and share environmental accessibility information for people with disabilities, it is not clear whether individuals from different user groups have similar or different behavior while contributing volunteered geographic information about environmental accessibility. In this paper, we present a case study to investigate how users (including elderly people, wheelchair users, blind and visually impaired people as well as volunteers) annotate environmental accessibility information in their journey. We found that subjects from different user groups had different behavior while annotating accessibility information and volunteers who do not have a disability are not good at spotting environmental accessibility issues. With these findings, we conclude a series of insights about how to collect collaborative environmental accessibility for designers and developers.

## 1 Introduction

As recently reported by the World Health Organization (WHO), over a billion people (about 15% of the world's population) have some form of disability [24]. Although a number of laws, recommendations and standards such as the *Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities*, and *German DIN 18040 barrier-free constructions*, are applied in different countries, in order to make urban and rural environments accessible for people with disabilities, it is time- and cost-consuming to reconstruct existing inaccessible buildings and facilities. In addition to accessing those inaccessible environments physically [2, 7], at present, it is challenging for people with disabilities to acquire environmental accessibility information in cyberspace, toward an independent and safe journey.

Due to the lack of environmental accessibility data on geographic features in geographic information systems (GIS), today's GPS-based navigation systems fail to provide personalized routes for people with special needs. For instance, most pedestrian route planners in navigation systems cannot avoid routes which contain stairs or curbs for wheelchair users. In recent years, several systems have been developed to collect varied environmental accessibility information by crowdsourcing approaches, such as the Wheelmap[1] system which gathers accessible features of points of interest (POIs) for wheelchair users, as well as the Access Together system[2]. It is true that user-contributed content can improve environmental accessibility in cyberspace; however, it is not clear whether such environmental information is appropriate and really helpful when considering different contributors' profiles and end users with different disabilities. One of the basic hypotheses of those crowdsourcing applications is that anyone's contributed content is helpful for the all. Nevertheless, while annotating for the same environment or scenario, users from

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1 http://wheelmap.org/.
2 http://www.accesstogether.org/.

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different groups (e.g., the elderly, the visually impaired and wheelchair users) might contribute varying content from their individual perspectives practically, and their contributed content might be helpful for the end users who are in the same group, though might not be helpful for other groups. Therefore, it is becoming an urgent issue to determine whether user profiles impact the behavior for annotating environmental accessibility and what the differences are.

To analyze user behavior while annotating environmental accessibility information, this paper describes a wizard-of-oz study with 36 subjects from four user groups, including elderly, visually impaired, wheelchair users and people without disabilities to investigate how people with special needs make annotations to enhance environmental accessibility while traveling. After presenting the results, we discuss several issues that occur when collecting environmental accessibility information and summarize a series of insights for designers and developers who work on environmental accessibility.

## 2 Related work

### 2.1 Acquisition of accessible route information on the move

Disabled people who have a visual capability may find accessible route information using their eyes while on the move, for example, where the stairs are and the status of a set of traffic light. Nevertheless, for blind and visually impaired people, it is challenging to acquire a series of accessible environmental information while traveling. In the last few decades, an array of computer-based assistive systems have been proposed and developed to help them acquire accessible environmental information while traveling, from varied electronic travel aids (ETAs) to detect obstacles [17, 21, 26] to systems for acquiring a traffic status in real time, e.g., a bus timetable [23] and traffic lights [4], to a number of camera-based systems for reading text [25] and navigating [14, 20]. In addition to computer-based systems, human-powered approaches also provide different types of accessible route information. Orientation & Mobility (O&M) experts describe the salient aspects of target routes (including accessibility issues and various barriers) to their visually impaired students, during the period of O&M trainings. In the ClickAndGo[3] system which offers seamless wayfinding solutions for disabled travelers, O&M experts not only provide specific turn-by-turn routes but also verbal descriptions of accessibility issues within the routes. However, it is time- and cost-consuming to invite experts to provide accessible annotations for millions of inaccessible geographic features. In recent years, the crowdsourcing concept has been applied in many fields, for instance, the OpenStreetMap[4] [8] uses volunteered geographic information to build a worldwide map in a low cost way. The wheelmap system and the Access Together system allow expert and non-expert contributors to create annotations about environmental accessibility. However, it is not clear whether the volunteered geographic information annotated by a large amount of non-expert volunteers is effective for people with different disabilities as well.

### 2.2 Collaborative accessible information in cyberspace

*Social media,* as a burgeoning form of interaction, has been impacting information society [1], as well as people who have special needs. At present, a large number of crowdsourcing applications have been implemented to improve the accessibility of various services for people with disabilities. To help visually impaired people read inaccessible images on web pages, the ALT-server project [5] and the Social Accessibility project [19] encourage sighted volunteers to contribute alternative text that can be accessed by screen-reader software or Braille displays. Through the crowdsourcing-based VizWiz system, blind people are able to acquire answers to their daily questions nearly in real time, with the help of sighted volunteers [3]. The CRISS system helps visually impaired people and sighted people to share and manage route descriptions collaboratively [18], and elderly people can work on proofreading together with young workers collaboratively [15].

### 2.3 Collaborative environmental accessibility information in the physical world

In addition to providing accessible information in cyberspace, it is important to improve the environmental accessibility of our society for individuals who have special needs, when they travel in cities, such as for the elderly to get bus timetables and for the blind to acquire the status of traffic lights. Although the concept of building inclusive and accessible cities has been widely accepted and is being executed by most countries, it does not mean that our environment will become barrier-free for all overnight. Therefore, a variety of assistive mobility tools have been used to help access environmental information, e.g., BlindSquare[5], SoNavNet [13] and COACH [27].

[3] http://www.clickandgomaps.com/.

[4] http://www.openstreetmap.org/.

[5] BlindSquare, www.blindsquare.com.

In the past decade, in the development of social media increasingly, more collaborative applications are being used to enhance environmental accessibility. Inspired by the concept of “Citizens as sensors” proposed by Goodchild [11] and the open source map provider OpenStreetMap, several collaborative map systems are collecting enhanced environmental accessibility information from volunteers, such as the Wheelmap system and the Access Together system. Ding et al. [6] listed several issues of the environmental accessibility data within those existing map systems, from the aspect of data structure. However, most of the existing map systems collect accessibility data for POIs (e.g., buildings and stations) within a geographic database and pay less attention to the surrounding environment such as stairs or curbs on a street while traveling. The previous studies did not indicate whether the accessibility annotations contributed by volunteers are desired by end users with different disabilities, in terms of safety, accessibility and effort.

Furthermore, in addition to volunteers’ contribution, disabled users would contribute and share their experiences as accessibility annotations. Kulyukin [16] proposed the concept of “the blind leading the blind” which allowed the blind community to share environmental accessibility information. However, few studies focus on whether disabled people from different groups would share their accessibility annotations on the environment with users from other groups. For example, the elderly users’ annotations for a pedestrian path are also valuable for blind and visually impaired users.

### 2.4 Inclusive navigation systems with collaborative environmental accessibility information

To help people with disabilities navigate independently and with a personalized route, several route planner prototypes take users’ profiles and accessible environmental information into account. The OurWay system [9] generates routes based on users’ ratings for the accessibility feature of a route segment; however, it only allows three simple rating levels, i.e., good, uncomfortable and inaccessible. The RouteCheckr system [22] considers users’ contributed data as multiple criteria ratings in terms of length, safety and accessibility, while calculating routes for mobility impaired pedestrians. However, these studies lack practical experiments with a large number of volunteers and end users (people with disabilities). Moreover, there are a few studies which focus on investigating how users annotate, share and utilize environmental accessibility in the real world. Goncalves et al. [10] presented how contextual cues (e.g., photos and locations) of geographic features impact contributors’ performances while assessing accessibility attributes by reviewing photos and maps remotely, rather than experiencing inaccessible spots personally.

As introduced above, there are already some VGI-based systems that collect environmental accessibility information. For example, in Table 1 five existing geo-crowd-sourcing-based systems are compared, in terms of target group, contributor, target geographic features and their annotation content. Nonetheless, there is no experimental study to investigate their behavior (e.g., preferences and quality) when contributors from different groups create enhanced environmental accessibility information. It is not clear whether their annotation behaviors are different and how different they are.

## 3 User study

In the present case study, we used a wizard-of-oz (WoZ)-based experimental setup, to study whether participants from different user groups (e.g., elderly people, wheelchair users and visually impaired people) have different behavior while annotating environmental accessibility and what the differences are.

### 3.1 Participants

We recruited 36 participants from four selected user groups: nine elderly participants aged 68–78 (*M* 72.3, SD 3.57), seven wheelchair users aged 19–71 (*M* 41.6, SD 17.7), 10 visually impaired subjects aged 20–31 (*M* 26.7, SD 3.40) and 10 volunteers without disabilities in a control group aged 22–58 (*M* 31.3, SD 13.66). Their gender was nearly balanced (female 20; male 16). Among the 10 visually impaired subjects, six participants were blind. All visually impaired participants used a white cane while traveling. Seven participants had no previous experience of GPS navigation systems, including five from the elderly group. Additionally, the 10 volunteer participants were recruited from our university.

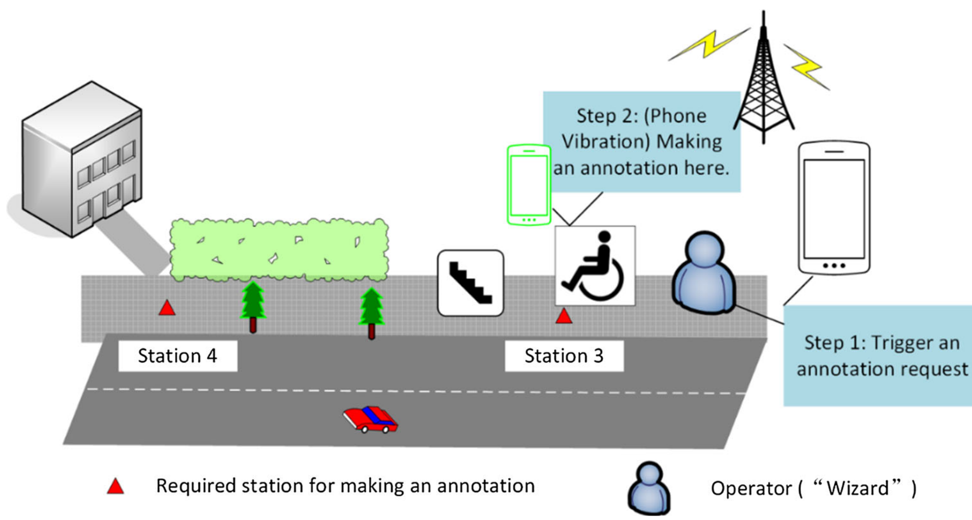
### 3.2 Method

Regarding the setup of the WoZ experiment, since GPS-based outdoor positioning does not permit an accuracy of less than 5 m (for instance, sometimes the GPS signal is weak or blocked by trees and high buildings), in this study a human operator, as a wizard, manually input and updated the participants’ positions. Using a human operator, an accuracy of about 1 m was achieved. Additionally, the wizard could trigger the mobile phone held by the participants (like a vibration), in order to ask the participants to annotate environmental accessibility at a current point in

**Table 1** A comparison of existing geo-crowdsourcing systems to enhance environmental accessibility

| Geo-crowdsourcing system | Target group | Contributor | Target geo-features | Content of VGI |
|---|---|---|---|---|
| ClickAndGo | Visually impaired users | O&M experts | POIs, routes | Unstructured verbal description |
| Wheelmap | Wheelchair users | Sighted volunteers | POIs | Structured ratings (3 levels) |
| Access Together | People with a disability | All volunteers | POIs | Unstructured text description |
| SoNavNet | People with a disability | Volunteers with experience | POIs, routes | Unstructured text description |
| COACH | Visually impaired users | O&M experts; all volunteers | POIs | Unstructured verbal and text description; structured mapping information |

**Fig. 1** Experimental setup of the wizard-of-oz study




time. This trigger was used in pre-defined locations and all participants were instructed to annotate upon request about all noticeable characteristics and to rate the location regarding pre-defined criteria such as structural accessibility. We used pre-defined locations to compare annotations gathered from the participants later during our analysis. In addition to the annotations requested in pre-defined locations, participants were allowed to annotate in any location at will.

Figure 1 illustrates how to make annotations at required stations. An operator walked behind the participants and had to keep a reasonable distance. When participants were approaching one of the required annotation stations, the operator triggered an annotation request on his/her mobile device. When they received a notification (i.e., vibrating the phone), the participants needed to make annotations about their experience of environmental accessibility. For example, the wheelchair user in Fig. 1 might add an annotation about the front stairs which obstructs wheelchair users, at Station 3 as one required annotation station. Meanwhile, the wheelchair user would annotate enhanced environmental accessible information freely at any sites on her/his way.

## 3.3 Preparation

### *3.3.1 Mobile clients*

Three touch-screen mobile phone clients with different user interfaces were implemented, for the remote operator, participants from the visually impaired group and participants from other user groups accordingly. Apart from setting the profile of the ongoing experiments through the mobile client, the remote operator could trigger the navigation event and send corresponding messages to the participants. The participants were guided by verbal navigation descriptions, e.g., turning left/right, as well as creating annotations at the sites. Regarding the mobile client for the visually impaired participants, several special touch gestures [12] have been developed to help them control the application and access text content via text-to-speech technology. Additionally, the participants from the elderly group, the wheelchair user group and the volunteer group could interact with the application via a graphic user interface.

### 3.3.2 *Test routes*

We selected a test route on a campus consisting of 10 required annotation stations (see Fig. 2). Table 2 describes the detailed environmental features at the requested annotation stations. Special signs have been marked on the ground for each required annotation station.

### 3.3.3 *Structure of an annotation*

In this study, an annotation consists of two parts: One part is a 5-point Likert scale rating question for different criteria and the other is a text-based comment which describes additional environmental information. Four important criteria of environmental features were selected to assess their overall accessibility, which were accessibility, safety, effort and orientation.

*Accessibility criterion* indicates the number of obstacles and barriers that have to be overcome;

*Safety criterion* states the safety while standing still in the position and going through;

*Effort criterion* indicates how much effort is needed to move on;

*Orientation criterion* indicates the ease to orientate themselves in the position.

To annotate the four criteria, 5-point Likert scale questions have been used (1 most positive, 5 most negative). In this study, we let elderly participants and wheelchair users rate for the criteria of accessibility, safety and effort, and visually impaired participants rate for the criteria of accessibility, safety and orientation. Volunteers in the control group were allowed to rate the four criteria.


**Fig. 2** Test route with 10 selected annotation sites

**Table 2** Main environmental features of requested annotation sites

| # station | Environmental feature | # station | Environmental feature |
|---|---|---|---|
| Site 1 | Loose surface; mailbox; without lowered edge; lawn edge; curb; power box; tram tracks | Site 6 | Narrow cobblestones; street sign; cigarette machine; lawn edge; curb; tram tracks |
| Site 2 | Loose surface; street sign; without lowered edge; lawn edge; curb | Site 7 | Narrow cobblestones; street sign; lawn edge; without lowered curbstone |
| Site 3 | Narrow cobblestones; lawn edge | Site 8 | Coarse cobblestones; slope, street sign; curb; exit |
| Site 4 | Slope; cobblestones; stairs; rough surface; special noise; exit | Site 9 | Narrow cobblestones; slope; curb |
| Site 5 | Slope; stairs; wall; railing; special noise | Site 10 | Coarse cobblestones; stairs. Intense odors; curb; special noise |

Subjects could input additional and detailed information about surrounding environmental features by typing or a voice recording.

## 3.4 Procedure

Referring to the ethical issues, before the experiments, the participants were informed of the test plans and their roles, as well as the use of their contributed data. The main evaluation parts were started when they agreed to perform the experiments. During the evaluation, we were permitted to make video recordings that were used for post-analysis.

In addition to training the wizard to use the mobile client, all participants were asked to learn how to use the corresponding mobile clients, the navigation messages, when and how to make an annotation, as well as the four criteria for annotating environmental features. After the training, the participants were led to the starting points and started to perform the main evaluation part. At the end of the evaluation, we conducted a structured interview with all participants, in which we asked about their experience with the system and their impression of the routes.

## 3.5 Independent variables and dependent measures

*Between-subject variables* In this study, demographics (i.e., the four user groups) was the between-subject variable. Participants from the four groups had different backgrounds and capabilities, as well as different special needs while traveling.

*Within-subject variables* There were two within-subject variables, the criteria for environmental features. Three criteria (i.e., accessibility, safety and effort) of environmental features were annotated by elderly subjects and wheelchair subjects, and accessibility, safety and orientation were the criteria which were offered for visually impaired participants. The control group would make annotations for the four criteria.

*Dependent measures* We counted the number of annotations which the subjects made on the requested sites and on route freely. Besides, the rating value for different environmental features was documented.

## 3.6 Results of annotation behavior

### *3.6.1 General annotation behavior*

All participants managed to find both routes by using our prototype navigation system. Furthermore, they all managed to use the annotation functions provided by the system. In total, elderly users entered 299 annotations, of which 104 were ratings regarding the pre-defined criteria and 195 were environmental features. Wheelchair users entered 277 annotations (147 ratings and 130 environmental features), visually impaired users entered 393 annotations (197 ratings and 195 environmental features) and users of the control group entered 470 annotations (273 ratings and 197 environmental features) in total. The elderly participants (*M* 33.2 annotations/person) and the visually impaired participants (*M* 39.3 annotations/person) annotated less than the wheelchair users (*M* 39.6 annotations/person) and the volunteers (*M* 47.0 annotations/person). The t-tests did not find significant differences in the mean number of annotations per person among each user group.

### *3.6.2 Number of annotations by different user groups*

The four groups had different annotation behavior while annotating for the four criteria. Figure 3 shows the distribution of ratings annotated by different user groups for the four pre-defined criteria. Elderly participants rated mostly regarding the safety criterion followed by the accessibility criterion, whereas the wheelchair group rated the accessibility criterion mostly. For the visually impaired participants, they not only had many more annotations than the elderly and wheelchair groups, but also mainly considered the orientation feature. Additionally, participants in the control group mostly focused on the criteria of safety and orientation. In the three criteria of accessibility, safety and

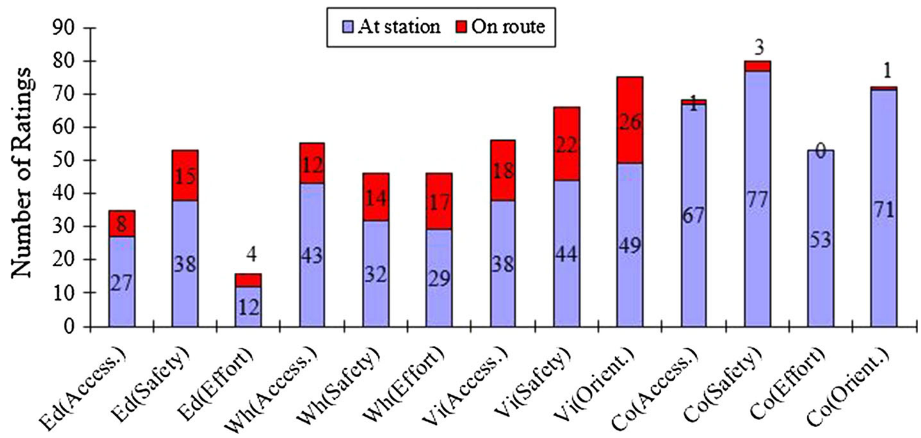



**Fig. 3** Number of ratings annotated at the 10 required stations and free sites on route (*Ed* the elderly group, *Wh* the wheelchair group, *Vi* the visually impaired group, *Co* the volunteer group)

effort, the Pearson's Chi-squared test found the elderly group, the wheelchair group and the control group had a significantly different total number of annotations ($p = 0.01$, at 95% confidence). The control group and the visually impaired group had no difference in the total number of annotations concerning the criteria of accessibility, safety and orientation.

The number of on-route ratings for the criterion of effort by elderly subjects is comparatively low (i.e., only 4), and the lack of ratings may be due to the participants who were mostly physically very healthy. Specifically, the control group only had five ratings annotated on route, compared with a large number of ratings at the 10 stations (268 ratings). There was no significant difference concerning the ratio found between the number of ratings annotated at stations and the number of ratings annotated on route, by the Pearson's Chi-squared test ($p = 0.36$, at 95% confidence), among the elderly group, the wheelchair group and the visually impaired group. The control group, however, had significantly different rating behavior at stations or on route ($p < 0.01$, at 95% confidence) to the other three groups.

The participants created a number of annotations about various environmental features they experienced while traveling (see Fig. 4). There were three main categories of these environmental features, consisting of visual features (e.g., street sign, cigarette machine, mailbox, etc.), surface-related features (e.g., cobblestone, loose and asphalt surface) and route-related features (e.g., stairs, slope and exit). Table 3 lists the four features which were annotated most frequently by the participants from the four groups, respectively. The cobblestone surface has been paid much more attention, specifically by the elderly, the visually impaired and the wheelchair group. Besides, the visually impaired subjects made annotations on several specific features (i.e., lawn edge, railing, wall, odor and sound) which were not considered by the other groups.

### 3.6.3 *Rating behavior by different user groups*

In addition, participants from different groups had different experiences and understanding of the four selected criteria, even at the same station. Figures 5, 6, 7 and 8 illustrate their mean ratings of the 10 targeted stations from the aspects of accessibility, effort, safety and orientation, respectively. Since all participants rated voluntarily either at 10 stations or on any sites while walking on the two routes, rather than imperatively for each item, we cannot obtain their complete rating for each criterion of each station to conduct a statistical analysis of the rating value. Thus, the mean rating value annotated at the 10 required stations is used to analyze whether the four groups have (significant) differences, by using the nonparametric-related Friedman Test (at 95% confidence). For the accessibility criterion, there was no difference between the elderly, the visually impaired and the wheelchair group; however, the control group mainly gave a different rating value to all of the other three groups ($p = 0.01$). The four groups had no difference in ratings' value for the safety criterion ($p = 0.12$). Regarding the effort criterion, it was found that the elderly and wheelchair participants gave similar ratings, while they had different ratings to the participants from the control group ($p = 0.02$). Moreover, for the orientation criterion, the control group and the visually impaired group had a significant difference in their mean rating value ($p < 0.01$).

## 3.7 Discussion

Although the volunteers from the control group were filled with passion to annotate environmental accessibility for people with special needs, they had different annotation behavior. For instance, the control group had significantly different rating behavior at stations or on route ($p < 0.01$, at 95% confidence) compared to the other three groups. Moreover, for the orientation criterion, the control group

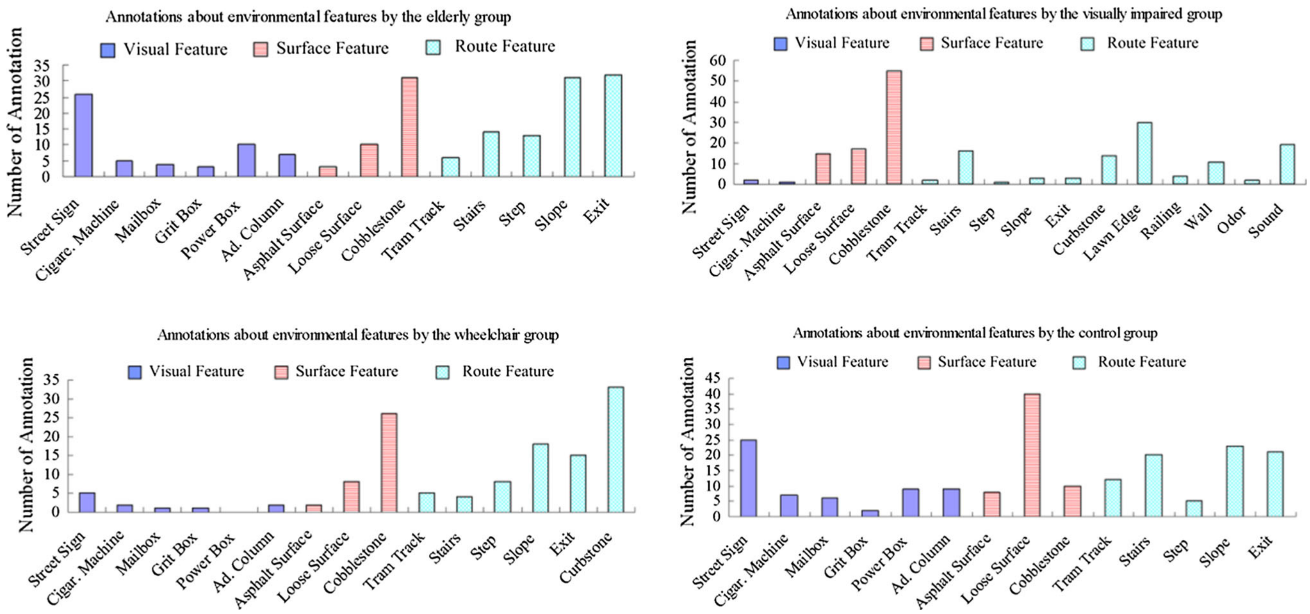
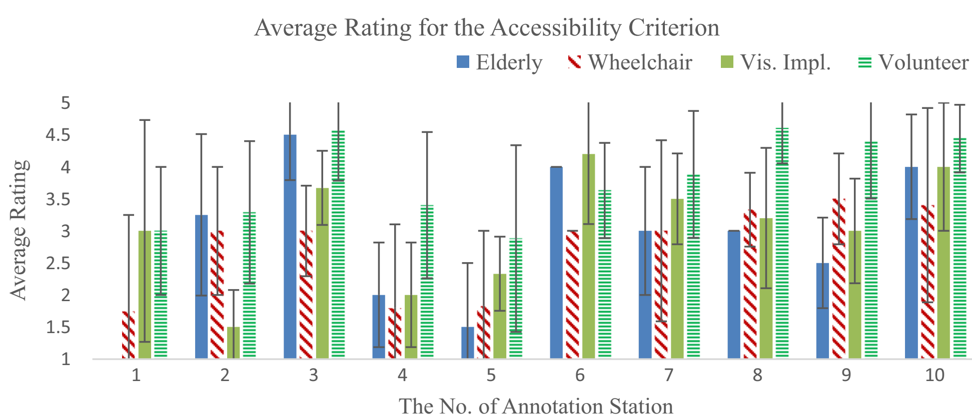



**Fig. 4** Number of annotations about environmental features by the participants

**Table 3** Four environmental features annotated most frequently by the participants

| # | Elderly group | Visually Impaired group | Wheelchair group | Control group |
|---|---|---|---|---|
| Top 1 | Cobblestone surface | Cobblestone surface | Curbstone | Loose surface |
| Top 2 | Exit | Lawn edge | Cobblestone surface | Street sign |
| Top 3 | Slope | Sound | Slope | Slope |
| Top 4 | Street sign | Loose surface | Exit | Stairs |

**Fig. 5** Participants' average rating for the accessibility criterion




and the visually impaired group also had a significantly different rating value ($p < 0.01$). Just like the participants from the control group, common volunteers as non-expert contributors who do not have enough accessibility knowledge might make many unexpected or useless annotations. Therefore, in a crowdsourcing system to improve the quality of volunteered geographic information about accessibility, it is necessary to invite experts to define the different attributes which should be annotated for different user groups, such as O&M experts. For example, the attribute about the tactile feeling of pedestrian paths is important for blind people, though the attribute about stairs, curbs and slopes demands more attention for wheelchair users. In addition to defining the attributes of environmental accessibility clearly and reasonably, it is important to guide and train volunteers on how to make usable annotations for people with different profiles.

Disabled users can also be contributors sometimes, specifically for end users from the same user group. It is appropriate that the annotations can be shared within the same user group, such as the blind leading the blind [16]. However, the kinds of content that can be shared among

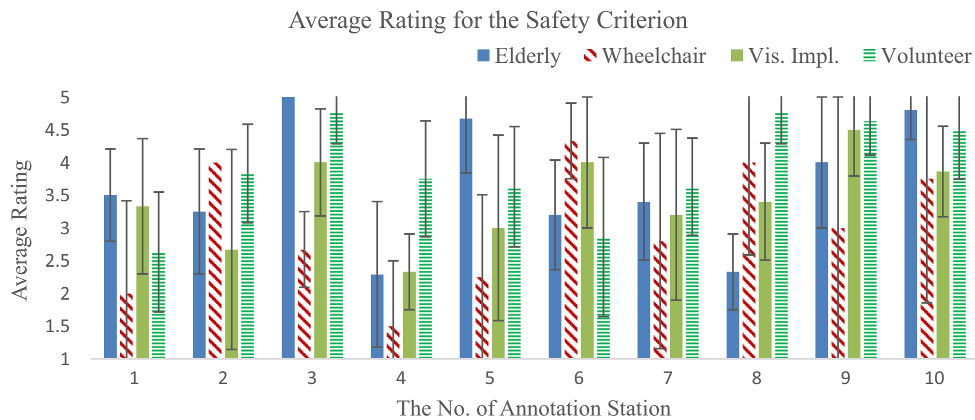



**Fig. 6** Participants' average rating for the safety criterion

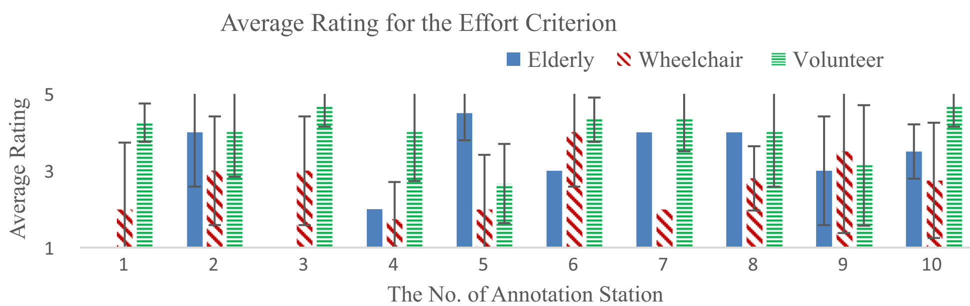



**Fig. 7** Participants' average rating for the effort criterion

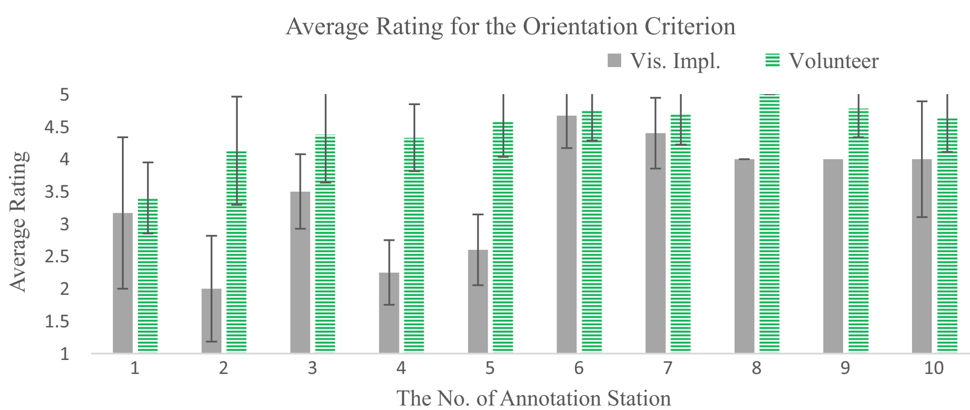



**Fig. 8** Participants' average rating for the orientation criterion

users from different groups are not clear, depending on different accessibility services.

## 4 Conclusions

In this paper, we have presented a case study to investigate different user behavior while contributing volunteered geographic information for accessibility, with 36 participants from different user groups (i.e., elderly people, wheelchair users, blind and visually impaired people, and volunteers). We found the participants from different user groups had different annotation behavior. Except for the required stations, the volunteers with no disability were not aware of where they should annotate. However, the participants with disabilities were more actively annotating on route. Furthermore, the volunteers had made different assessments of environmental accessibility in the real world, compared to the participants with disabilities, with regard to accessibility, effort and orientation, except the safety criterion.

Through these findings within the case study, we conclude a series of insights which would be useful for designers and developers who work on environmental accessibility:

1. People without disabilities can play the role of a volunteer who contributes environmental accessibility information; however, they need appropriate guidance from the crowdsourcing systems. Considering a lack of

knowledge about special needs in individuals with different disabilities, most commonly, volunteers as non-expert contributors do not know where to make a contribution and what should be annotated. It is important to let disabled users clearly point out what should be annotated. For example, in a system, disabled users would submit their requests to volunteers when they want to know environmental information. Moreover, a short introduction or training about how to rate the accessibility attributes of different geographic features will improve the quality of common volunteers' contributions.
2. People with disabilities can also be contributors to collect and share environmental accessibility information. They would initiatively make annotations in advance where they think, without requests from others.
3. In addition to unstructured annotations (e.g., text messages and voice recordings), structured annotations should also be collected in order to generate personalized routes which take volunteered geographic information or environmental accessibility into account. For instance, in the COACH system [27], the structured and unstructured annotations, such as environmental accessibility information contributed from volunteers, would help blind people navigate in unfamiliar regions.
4. The volunteer-driven collaborative systems for collecting environmental accessibility should consider different user profiles (e.g., capabilities and requirements) of the end users. The definition of accessibility attributes of geographic features should depend on geographic features and target user groups. Equally important, O&M experts should be involved in the processing while designing the accessibility attributes. Even for the same geographic feature, the accessibility attributes can be different. As a good example, the Access Together system allows users to contribute different attributes for people with different disabilities. Besides, it is valuable to draft a standard or a guideline to define the accessibility attributes of geographic features in the future.

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